USE OF COAL DRYING TO REDUCE WATER CONSUMED IN PULVERIZED COAL POWER PLANTS

QUARTERLY REPORT FOR THE PERIOD October 1, 2004 to December 31, 2004

by

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ABSTRACT

This is the eighth Quarterly Report for this project. The background and technical justification for the project are described, including potential benefits of reducing fuel moisture, prior to firing in a pulverized coal boiler.

Analyses were performed to determine the effects of coal product moisture on unit performance. Results are given showing how the coal product moisture level affects parameters such as boiler efficiency, power required to drive the fluidizing air fan, other station service power needed for fans and pulverizers, net unit heat rate, thermal energy rejected by the cooling tower, and stack emissions.

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INTRODUCTION

Background

Low rank fuels such as subbituminous coals and lignites contain significant amounts of moisture compared to higher rank coals. Typically, the moisture content of subbituminous coals ranges from 15 to 30 percent, while that for lignites is between 25 and 40 percent, where both are expressed on a wet coal basis.

High fuel moisture has several adverse impacts on the operation of a pulverized coal generating unit. High fuel moisture results in fuel handling problems, and it affects heat rate, mass rate (tonnage) of emissions, and the consumption of water needed for evaporative cooling.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. In particular, the project involves use of power plant waste heat to partially dry the coal before it is fed to the pulverizers. Done in a proper way, coal drying will reduce cooling tower makeup water requirements and also provide heat rate and emissions benefits.

The technology addressed in this project makes use of the hot circulating cooling water leaving the condenser to heat the air used for drying the coal (Figure 1). The temperature of the circulating water leaving the condenser is usually about 49°C (120°F), and this can be used to produce an air stream at approximately 43°C (110°F). Figure 2 shows a variation of this approach, in which coal drying would be accomplished by both warm air, passing through the dryer, and a flow of hot circulating cooling water, passing through a heat exchanger located in the dryer. Higher temperature drying can be accomplished if hot flue gas from the boiler or extracted steam from the turbine cycle is used to supplement the thermal energy obtained from the circulating cooling water. Various options such as these are being examined in this investigation.

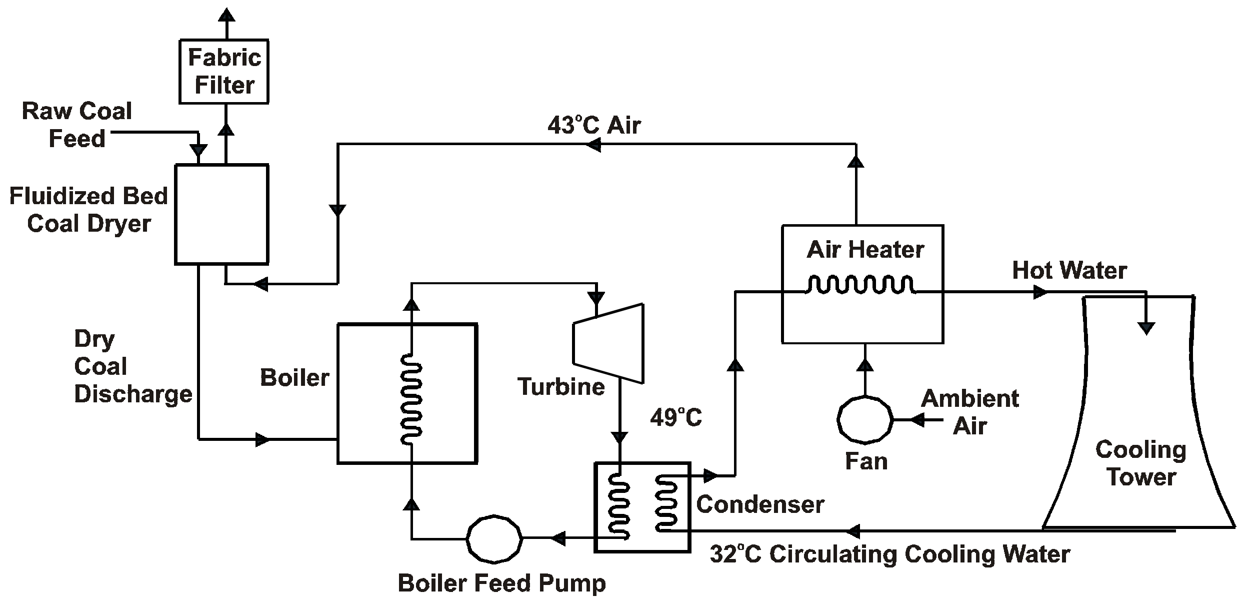

Figure 1: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 1)

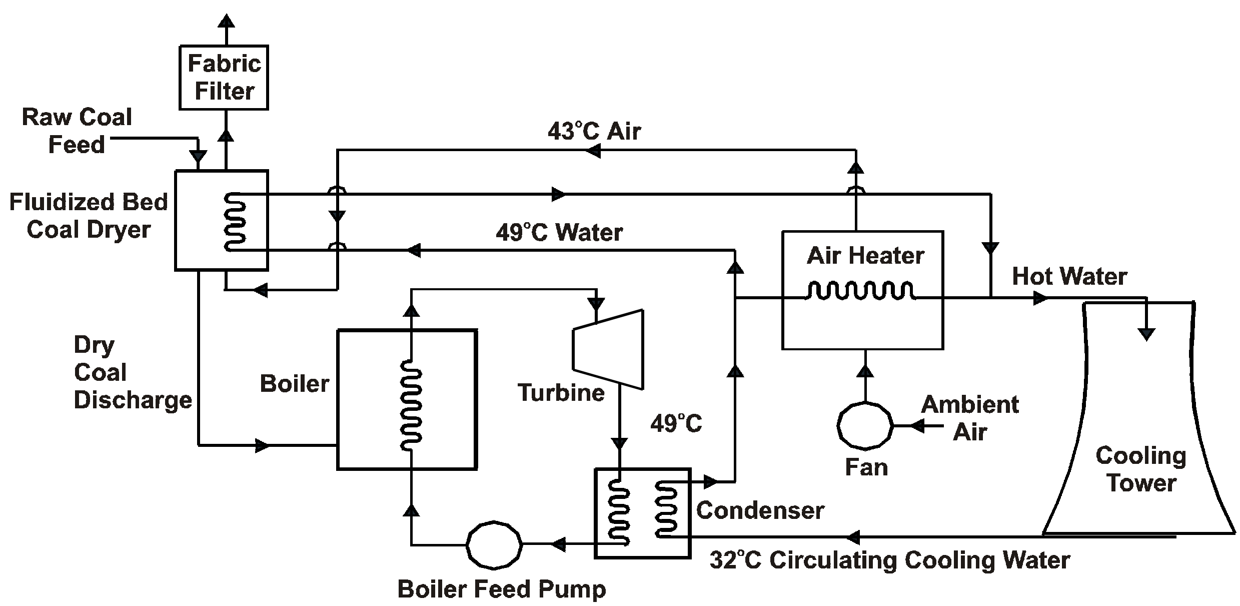

Figure 2: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 2)

Previous Work

Two of the investigators (Levy and Sarunac) have been involved in work with the Great River Energy Corporation on a study of low temperature drying at the Coal Creek Generating Station in Underwood, North Dakota. Coal Creek has two units with total gross generation exceeding 1,100 MW. The units fire a lignite fuel containing approximately 40 percent moisture and 12 percent ash. Both units at Coal Creek are equipped with low NO_x firing systems and have wet scrubbers and evaporative cooling towers.

A coal test burn was conducted at Coal Creek Unit 2 in October 2001 to determine the effect on unit operations. The lignite was dried for this test by an outdoor stockpile coal drying system. On average, the coal moisture was reduced by 6.1 percent, from 37.5 to 31.4 percent. Analysis of boiler efficiency and net unit heat rate showed that with coal drying, the improvement in boiler efficiency was approximately 2.6 percent, and the improvement in net unit heat rate was 2.7 to 2.8 percent. These results are in close agreement with theoretical predictions (Figure 3). The test data also showed the fuel flow rate was reduced by 10.8 percent and the flue gas flow rate was reduced by 4 percent. The combination of lower coal flow rate and better grindability combined to reduce mill power consumption by approximately 17 percent. Fan power was reduced by 3.8 percent due to lower air and flue gas flow rates. The average reduction in total auxiliary power was approximately 3.8 percent (Ref. 1).

This Investigation

Theoretical analyses and coal test burns performed at a lignite fired power plant show that by reducing the fuel moisture, it is indeed possible to improve boiler performance and unit heat rate, reduce emissions and reduce water consumption by the evaporative cooling tower. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

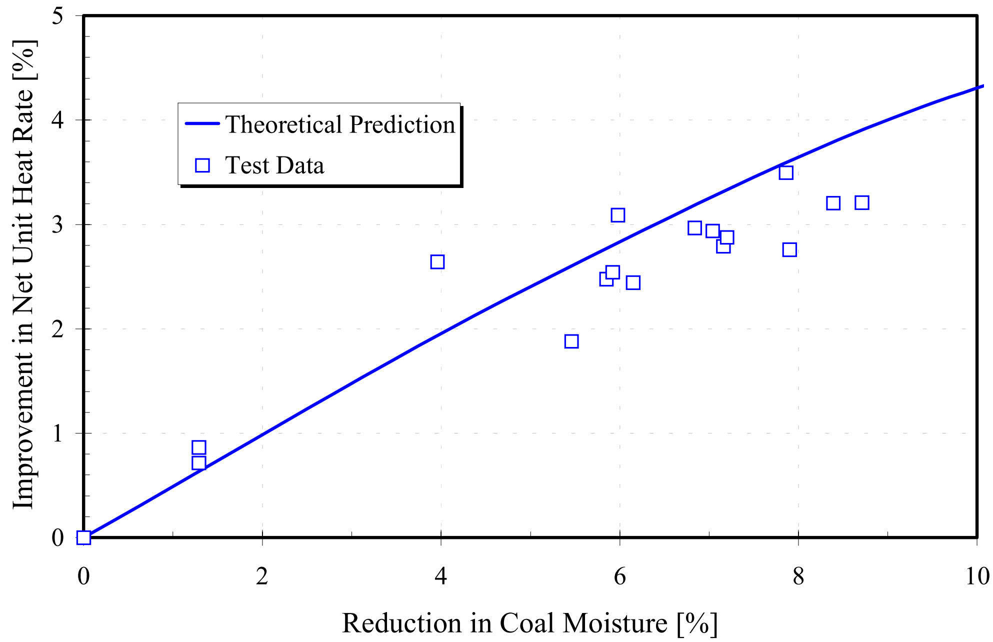

Figure 3: Improvement in Net Unit Heat Rate Versus Reduction in Coal Moisture Content

The present project is evaluating low temperature drying of lignite and Power River Basin (PRB) coal. Drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of the various drying options, along with the development of an optimized system design and recommended operating conditions.

The project is being carried out in five tasks. The original Task Statements included experiments and analyses for both fluidized bed and fixed bed dryers (see previous Quarterly Reports). After the project was started, it became clear there is no advantage to using fixed bed dryers for this application. For this reason, the technical scope was changed in June 2004 to emphasize fluidized bed drying. The Task Statements in this report reflect this change in emphasis.

Task 1: Fabricate and Instrument Equipment

A laboratory scale batch fluidized bed drying system will be designed, fabricated and instrumented in this task. **(Task Complete)**

Task 2: Perform Drying Experiments

The experiments will be carried out while varying superficial air velocity, inlet air temperature and specific humidity, particle size distribution, bed depth, and in-bed heater heat flux. Experiments will be performed with both lignite and PRB coals. **(Task Complete)**

Task 3: Develop Drying Models and Compare to Experimental Data

In this task, the laboratory drying data will be compared to equilibrium and kinetic models to develop models suitable for evaluating tradeoffs between dryer designs. **(Task Complete)**

Task 4: Drying System Design

Using the kinetic data and models from Tasks 2 and 3, dryers will be designed for lignite and PRB coal-fired power plants. Designs will be developed to dry the coal by various amounts. Auxiliary equipment such as fans, water to air heat exchangers, dust collection system and coal crushers will be sized, and installed capital costs and operating costs will be estimated**. (Task in Progress)**

Task 5: Analysis of Impacts on Unit Performance and Cost of Energy

Analyses will be performed to estimate the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power, and stack emissions. The cost of energy will be estimated as a function of the reduction in coal moisture content. Cost comparisons will be made between dryer operating conditions (for example, drying temperature and superficial air velocity). **(Task in Progress)**

EXECUTIVE SUMMARY

Background

Low rank fuels such as subbituminous coals and lignites contain relatively large amounts of moisture compared to higher rank coals. High fuel moisture results in fuel handling problems, and it affects station service power, heat rate, and stack gas emissions.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. The project involves use of the hot circulating cooling water leaving the condenser to provide heat needed to partially dry the coal before it is fed to the pulverizers.

Recently completed theoretical analyses and coal test burns performed at a lignite-fired power plant showed that by reducing the fuel moisture, it is possible to reduce water consumption by evaporative cooling towers, improve boiler performance and unit heat rate, and reduce emissions. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

This project is evaluating alternatives for the low temperature drying of lignite and Power River Basin (PRB) coal. Laboratory drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of drying, along with the development of an optimized system design and recommended operating conditions.

Results

Analyses were performed to estimate the effects on the operation of a power plant of using power plant waste heat to dry coal prior to feeding the coal to the pulverizers.

The results presented in this report were obtained from analyses of four different drying systems with a lignite coal having a 38.5 percent feed moisture. These show that while there are some differences due to drying system design, use of power plant waste heat to reduce coal moisture typically would result in improvements in boiler efficiency, net unit heat rate and in some components of the station service power. For constant electrical generation, this would result in reduced emissions of CO_2 and SO_2, and it most likely would also result in reduced NO_x and Hg emissions. For units with electrostatic precipitators, the reduction in flue gas flow rate due to firing a dryer coal would tend to reduce stack opacity. Finally, for units cooled by evaporative cooling towers, use of waste heat from the steam condenser for coal drying would reduce the makeup water requirements for the cooling tower.

DRYING SYSTEM DESIGN AND ANALYSIS OF IMPACTS ON UNIT PERFORMANCE AND COST OF ENERGY

Background

Tasks 4 and 5 involve the design of drying systems for 570 MW lignite and PRB coal-fired power plants, analysis of the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power and stack emissions, and estimation of the cost of energy as a function of reduction in coal moisture content and dryer design. The work in these two tasks is progressing in the following subtasks:

Subtask 1: Estimate effects of firing dried coal on flow rates of combustion air and flue gas, required feed rate of coal to boiler, mill and fan power, boiler efficiency and unit heat rate. **(Complete)**

Subtask 2: Estimate required dryer size, flow rates of fluidizing air and amount of in-bed heat transfer as functions of drying temperature and coal product moisture. **(Complete)**

Subtask 3: Integrate dryer into boiler and turbine cycle and calculate overall impacts on heat rate, evaporative cooling tower makeup water and emissions. **(In Progress)**

Subtask 4: Size remaining components and develop drying system cost estimates. **(In Progress)**

Subtask 5: Perform calculations to select optimal drying system configuration and product coal moisture.

Drying System Options

During this last Quarter, the effort was focused on Subtasks 3 and 4. There are several sources of waste heat in a typical power plant having a pulverized coal boiler and a steam cycle. These make it possible to obtain heat for drying from the boiler, from one of the many steam flows in the turbine cycle, and/or from the hot cooling water leaving the steam condenser.

The drying scheme, shown in Figure 2, involves fluidized bed dryers, where waste heat from the steam condenser is used to preheat the fluidization air and provide additional heat for drying using in-bed heat exchangers. Coal is fed to the dryers and is then transported with reduced moisture to the pulverizers before being conveyed to the burners by transport air. After leaving a dryer, the fluidization air must pass through a baghouse to remove elutriated coal particles. Besides the fan for the fluidization air, other equipment requiring station service power includes the coal crushers, pulverizers, and forced draft and induced draft fans.

Since the steam condenser typically operates with steam temperatures in the vicinity of 49°C, the fluidization air and in-bed drying coil in the system illustrated in Figure 2 are limited to temperatures of about 43°C. The size of the dryer, flow rate of fluidizing air and the power required to drive the fluidizing air fan, are strong functions of dryer operating temperature. Higher dryer temperatures can be obtained by making use of higher temperature sources of waste heat from the boiler and turbine cycle.

Impacts of Drying

Figures 4 through 13 show predicted results on the effects of coal drying on power plant operations using four different drying system designs, referred to here as A, B, C and D. These analyses are for a power generation unit having a design value of gross electrical generation of 572 MW. The fuel is a lignite with a feed moisture of 38.5 percent (mass water/mass wet coal) and it is assumed the flue gas leaves the economizer at 343°C.

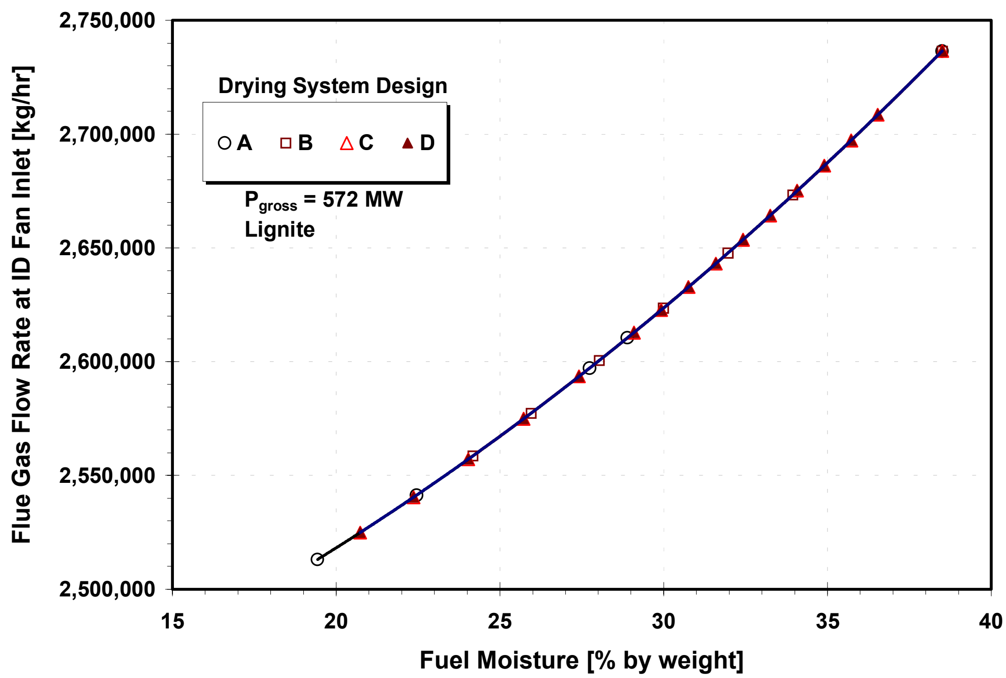

Figure 4: Flue Gas Flow Rate.

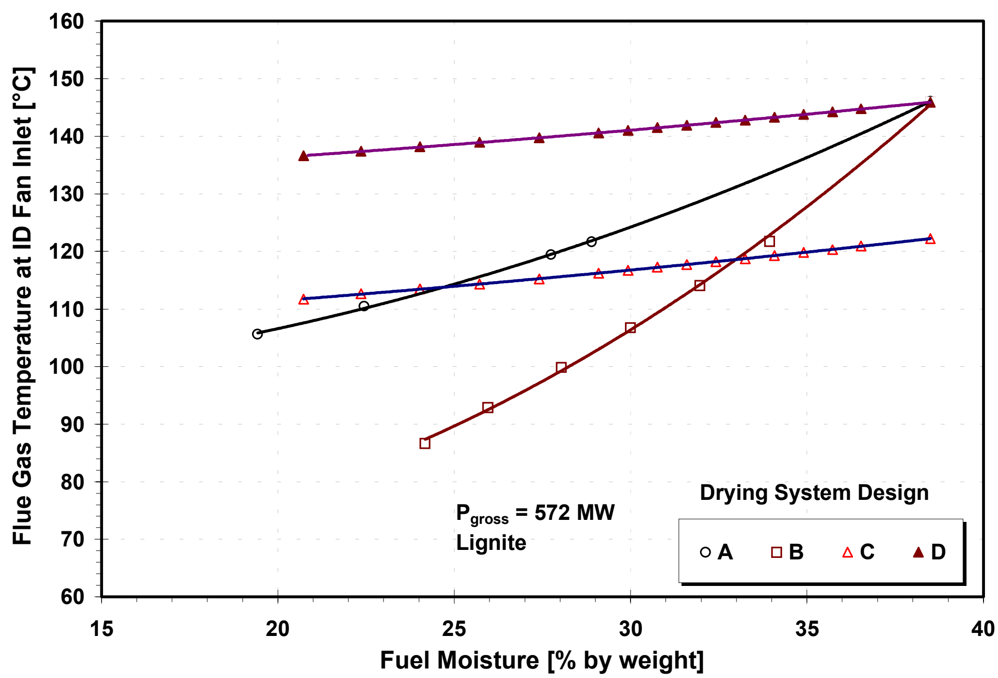

Figure 5: Flue Gas Temperature Entering ID Fan. $T_{ECO,go}$ = 343°C.

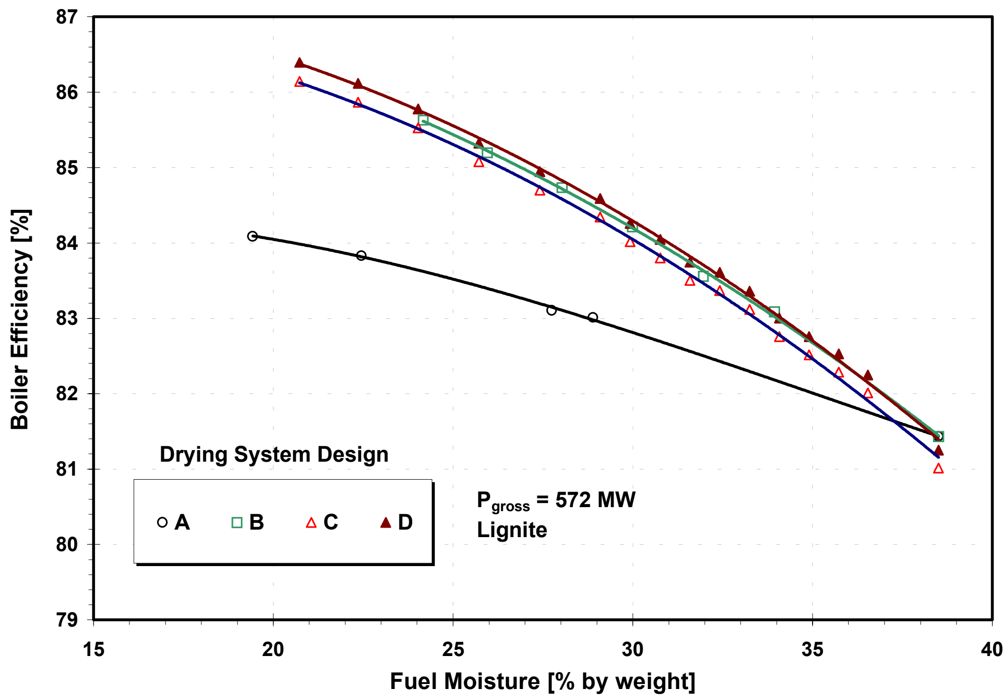

Figure 6: Boiler Efficiency.

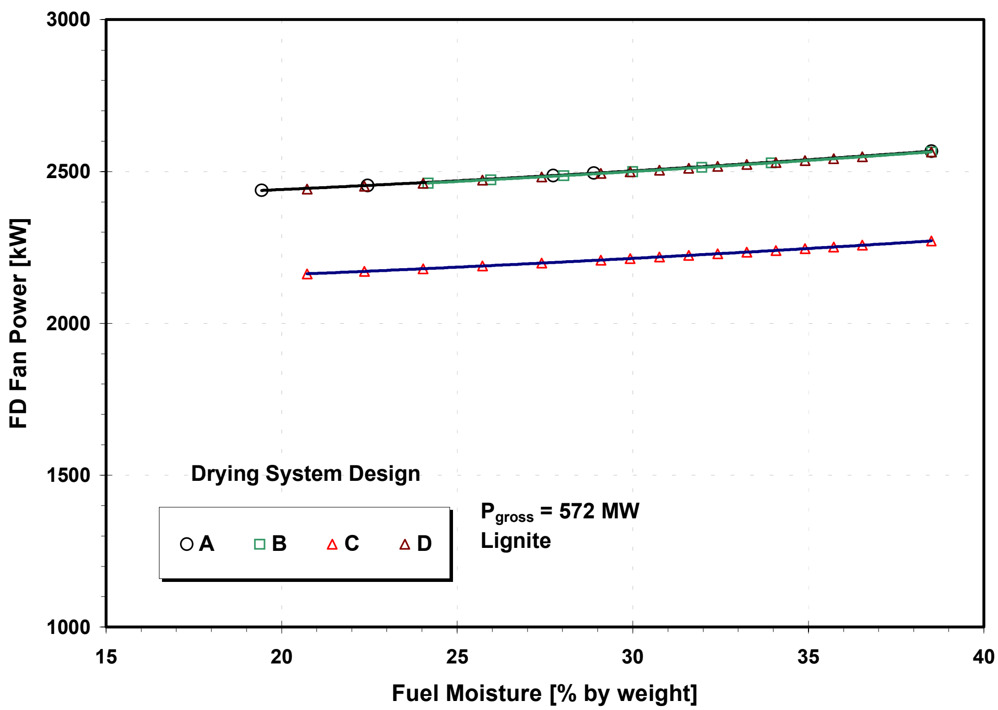

Figure 7: FD Fan Power.

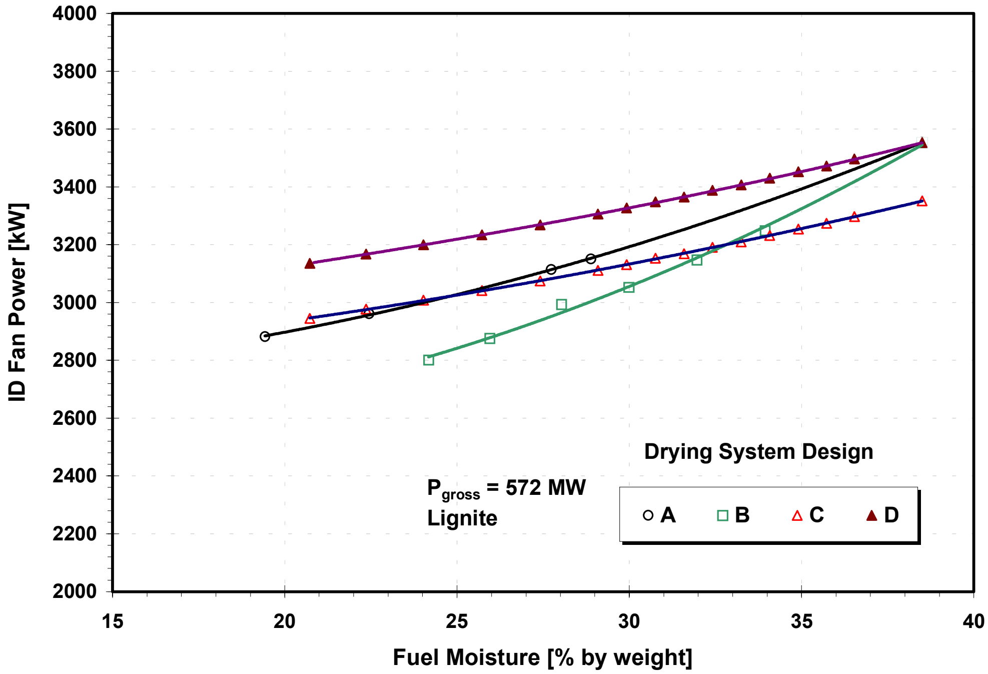

Figure 8: ID Fan Power.

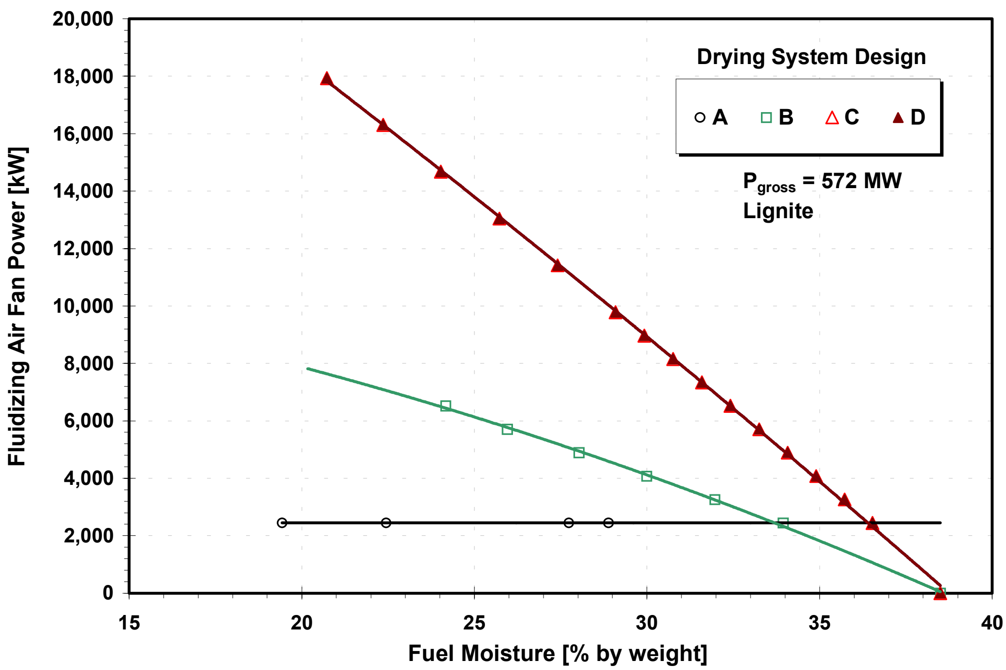

Figure 9: Fluidizing Air Fan Power.

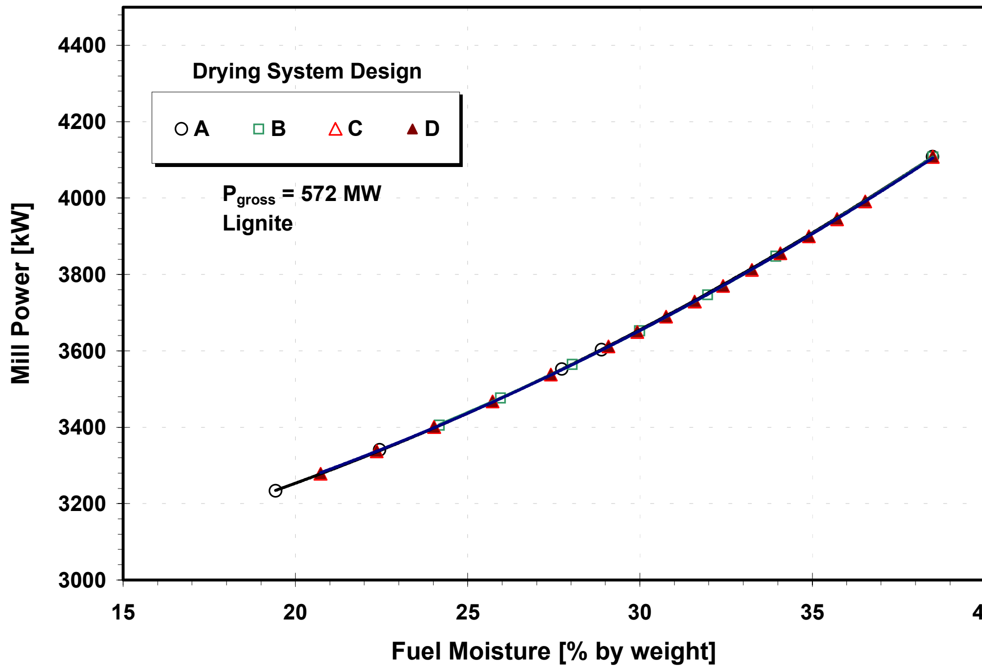

Figure 10: Mill Power.

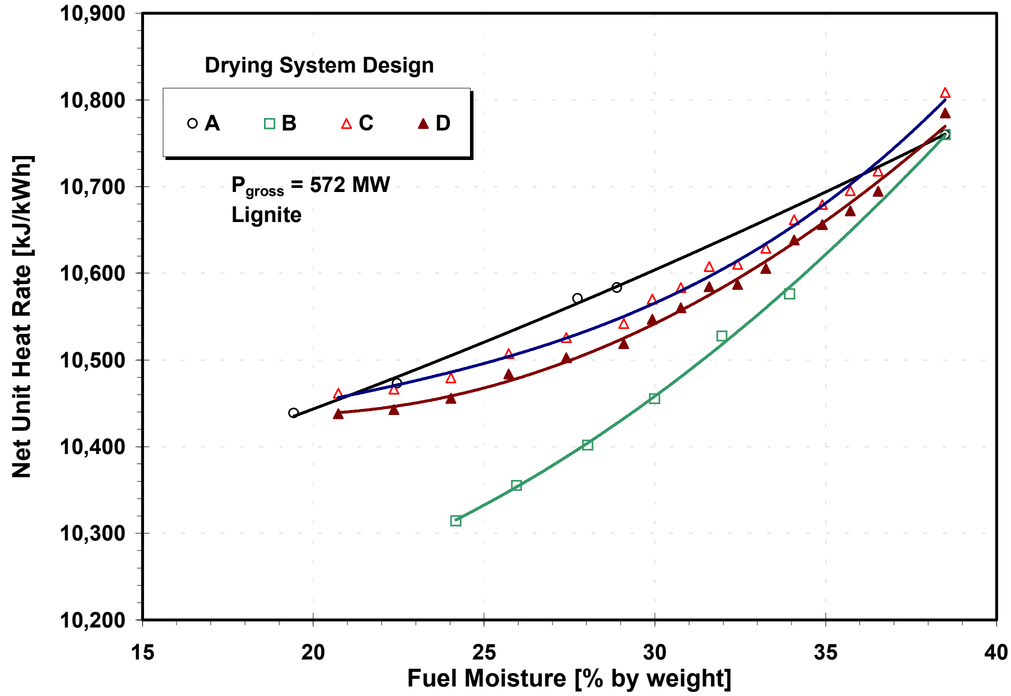

Figure 11: Net Unit Heat Rate.

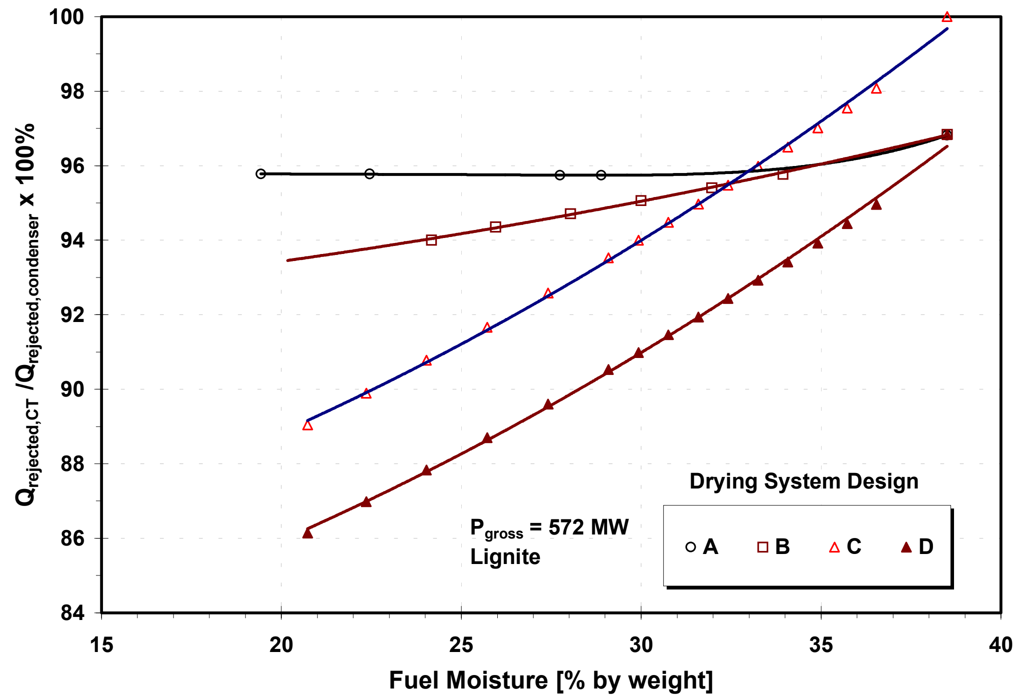

Figure 12: Ratio of Heat Rejected by Cooling Tower to Heat Rejected by Steam Condenser.

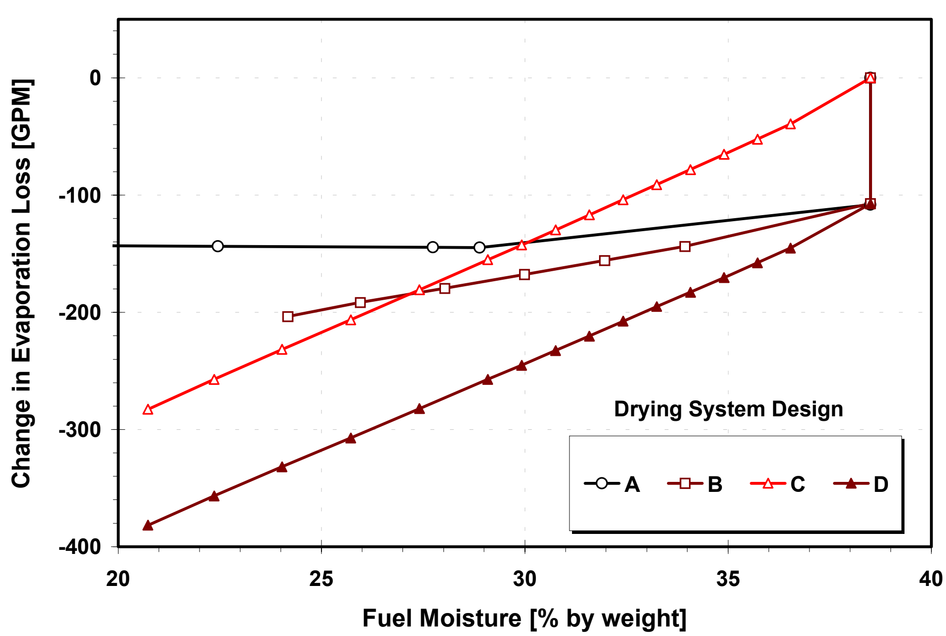

Figure 13: Reduction in Cooling Tower Water Evaporation Loss.

For this situation, boiler efficiency depends primarily on flue gas flow rate and temperature at the stack. Figures 4 and 5 show the flue gas flow rate and temperature as functions of coal moisture leaving the dryer. While the flue gas flow rate does not depend on the configuration of the drying system, the back end temperature is quite sensitive to drying system design. The results for boiler efficiency, Figure 6, show the efficiency increases with a reduction in coal moisture, with some differences due to type of drying system.

The ID and FD fan power are both reduced as the coal moisture decreases (Figures 7 and 8). Less FD fan power is required due to the reductions in coal flow rate and combustion air caused by an improvement in heat rate. While the ID fan power decreases with a decrease in coal moisture due to the decrease in flue gas flow rate, it also is affected by flue gas temperature and thus varies with drying system design. In general, the fluidizing air fan power (Figure 9) increases with a decrease in coal product moisture, since the power increases with the size of the dryer and thus fluidizing air flow rate. This quantity is quite sensitive to drying system design. The other component of station service power affected by coal drying is mill power, which depends on coal product moisture (Figure 10) and on pulverizer design.

Net unit heat rate, which is defined as

$$HR_{net} = \frac{\dot{Q}_{fuel}}{P_g - P_{ss}} = \frac{HR_{cycle,gross} \times P_g}{\eta_B \left(P_g - P_{ss}\right)}$$

where boiler efficiency, gross cycle heat rate and net electrical generation are:

$$\eta_B = \frac{\dot{Q}_T}{\dot{Q}_{fuel}}$$

$$HR_{cycle,gross} = \frac{\dot{Q}_T}{P_g}$$

and $P_{net} = P_g - P_{ss}$,

can be calculated once information is available on boiler efficiency and total station service power. The net unit heat rate, shown in Figure 11, decreases with a reduction in coal moisture. With the coal feed at 38.5 percent moisture and a product moisture of 20 percent, the predicted improvement in heat rate ranges from 3.1 to 5.2 percent, depending on the type of drying system. The calculations also show the impact of drying on improvement in heat rate also depends on flue gas temperature leaving the economizer. The gains in heat rate range from 5.7 to 8 percent for an economizer exit gas temperature of 441°C.

The improvements in net unit heat rate shown in Figure 11 also result in reductions in emissions of some stack pollutants. For a fixed net power output, the coal flow rate is proportional to net unit heat rate, and thus the SO_2 and CO_2 emissions, which depend on coal flow rate, vary directly with heat rate. NO_x and Hg emissions vary with coal flow rate and the concentrations of Hg and NO_x in the flue gas at the stack. There is evidence from laboratory tests and theoretical calculations performed at Lehigh that the stack gas Hg concentration decreases with a decrease in flue gas moisture. Similarly, for many boiler designs, NO_x concentration varies with combustor flame temperature, which, in turn, is affected by flue gas moisture content. While it appears both NO_x and Hg emissions will be lower with a dryer coal, full-scale field tests are needed to determine the effects of coal drying on the magnitudes of the changes in these two pollutants. Finally, drying should have a beneficial effect on electrostatic precipitator efficiency due to the decrease in flue gas flow rate and coal feed rate.

For units with evaporative cooling towers, coal drying can also be used to reduce the tower makeup water requirements. Figure 12 shows the fraction of the heat rejected by the condenser which must be rejected by the cooling tower. This then translates into a reduction in tower makeup water as shown in Figure 13. For the specific cases analyzed here, up to 0.55×10^6 gallons/day (2.08×10^6 liters/day) would be saved due to drying the coal to 20 percent moisture.

Summary and Conclusions

Analyses were performed to estimate the effects on the operation of a power plant of using power plant waste heat to dry coal prior to feeding the coal to the pulverizers.

The results presented in this paper were obtained from analyses of four different drying systems with a lignite coal having a 38.5 percent feed moisture. These show that while there are some differences due to drying system design, use of power plant waste heat to reduce coal moisture typically would result in improvements in boiler efficiency, net unit heat rate and in some components of the station service power. For constant electrical generation, this would result in reduced emissions of CO_2 and SO_2, and it most likely would also result in reduced NO_x and Hg emissions. For units with electrostatic precipitators, the reduction in flue gas flow rate due to firing a dryer coal would tend to reduce stack opacity. Finally, for units cooled by evaporative cooling towers, use of waste heat from the steam condenser for coal drying would reduce the makeup water requirements for the cooling tower.

PLANS FOR NEXT QUARTER

During the next quarter, work will continue on the Task 4 and 5 drying system analyses for lignite. Drying system analyses will also be carried out for a Powder River Basin coal. The projected impacts on emissions and cooling tower makeup water will be determined and work will continue on gathering cost data for components such as heat exchangers, fans and fluidized bed dryers. The cost data will be combined to provide estimates of capital and operating costs.

NOMENCLATURE

C	Coal Moisture (wet basis)
M_{air}	Air Flow Rate
M_{coal}	Coal Flow Rate

P_g	Gross Electrical Power
P_{ss}	Station Service Power
P_{net}	Net Electrical Power
Q	Rate of Heat Transfer
T	Temperature

Abbreviations

APH	Air Preheater
CA	Combustion Air
FA	Fluidizing Air
FB	Fluidized Bed
FD	Forced Draft
gi	Gas Inlet
HCW	Hot Circulating Cooling Water
ID	Induced Draft

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